

MSAT MOBILE ELECTRONICALLY STEERED PHASED ARRAY ANTENNA DEVELOPMENT

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ABSTRACT

The MSAT-X breadboard antenna design demonstrates the feasibility of utilizing a phased array in a mobile satellite application. An electronically steerable phased array capable of tracking geosynchronous satellites from anywhere in the Continental United States has been developed. The design is reviewed, along with test data. Cost analyses are presented which indicate that this design (when optimized for volume production) can be produced at a cost of \$1620 per antenna.

INTRODUCTION

Ball Aerospace Systems Division developed a breadboard electronically steered phased array antenna for use in the MSAT-X mobile telephone communications system. The antenna transmit and receive bands are 1646.5-1660.5 MHz and 1545.0-1559.0 MHz, respectively. The antenna gain requirement is 10 dBic (RHCP) in the direction of the satellite throughout the coverage region (0-360 degrees in azimuth, 20-60 degrees in elevation). The ultimate goal of the program effort is to develop an antenna which meets the specs in addition to being manufacturable, reliable, and economical, in order to meet the needs of the MSAT end user.

DESIGN

The mounting configuration for the MSAT-X system is shown in Figure 1. The phased array is mounted on the car roof and the pointing system electronics are mounted in the trunk, along with the transceiver. The system block diagram is shown in Figure 2. The beam steering computer consists of a single-board PC clone and associated interface circuitry. This will be replaced with an 8086-based microprocessor system or single-chip microcontroller in later versions. The beam steering computer performs all antenna acquisition and tracking functions. For acquisition, the antenna scans a pattern of 48 beam positions, (every 15 degrees in azimuth, for two different elevations). Multipath and fading effects are minimized by taking a series of

FIGURE 1 MSAT-X ANTENNA SYSTEM

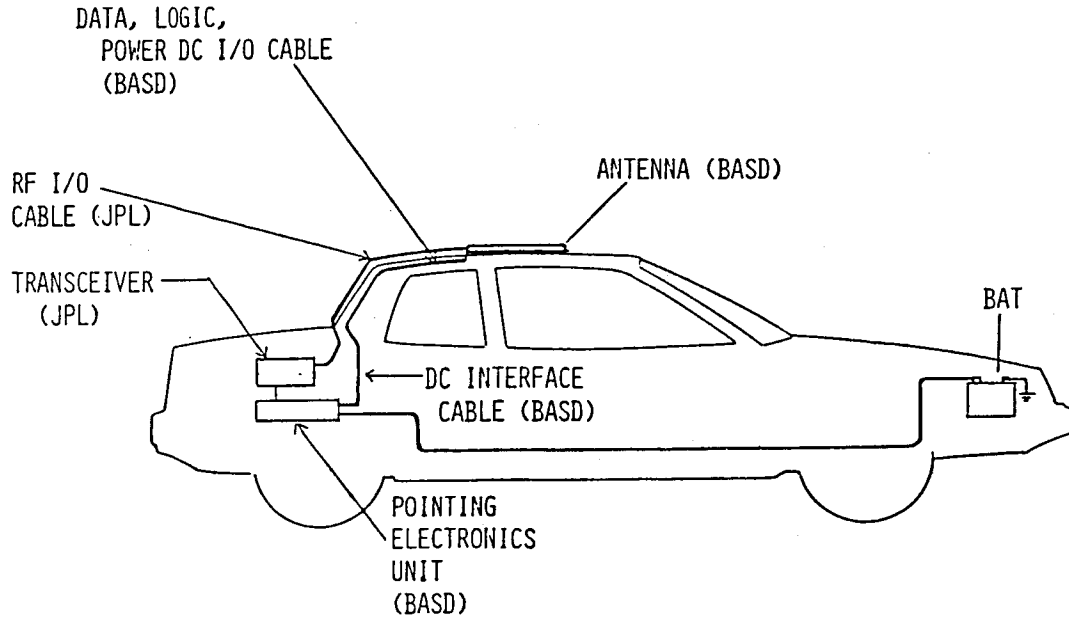
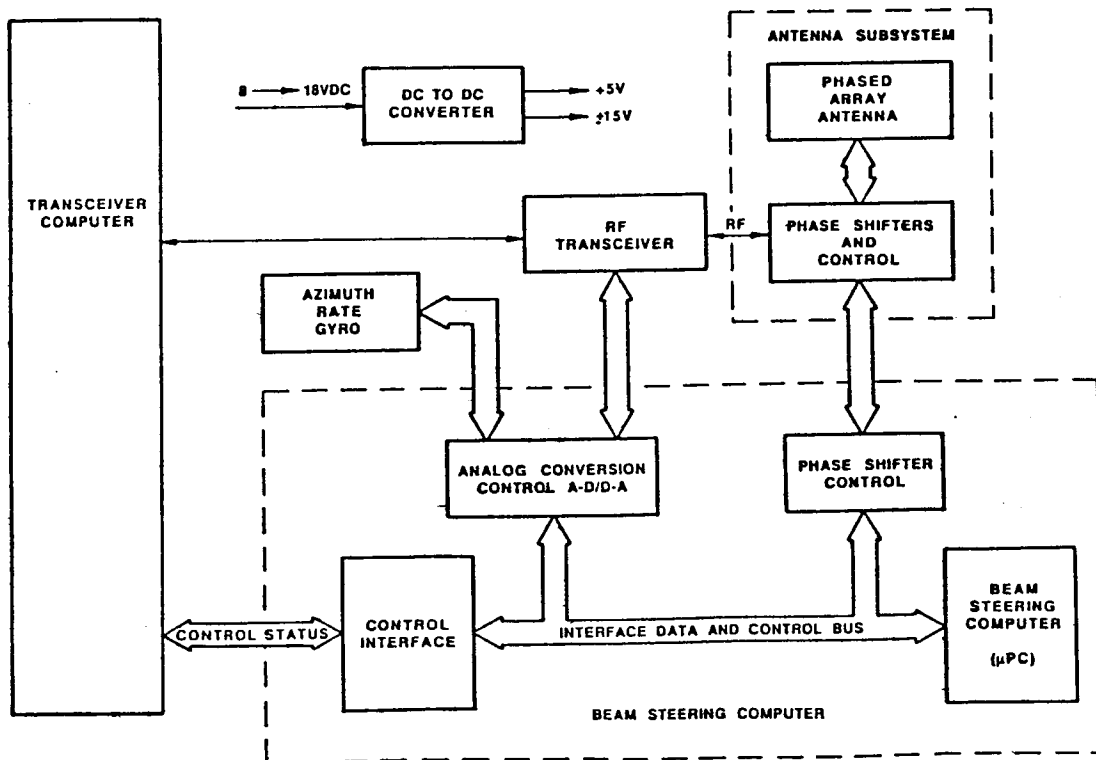


FIGURE 2 MSAT SYSTEM FUNCTIONAL BLOCK DIAGRAM



scans over a two-second acquisition period and averaging the results. In order to keep vehicle motion from distorting the scan data, the scan pattern is taken in reference to an inertially-fixed coordinate system, established using the azimuth rate sensor. Tracking is accomplished using a combination of closed-loop and open-loop control. The primary tracking mode is closed-loop tracking. In this mode, the beam is dithered about the satellite position in a diamond-shaped sequential lobing pattern at a rate significantly higher than the required pointing update rate. This allows a number of dither measurements (about 100) to be averaged in computing the satellite position. By dithering at a rate significantly higher than the maximum multipath rate, the tracking error due to multipath is virtually eliminated. Open loop tracking is conducted using information from the angular rate gyro. This is quite useful for maintaining pointing during short signal outages (10 seconds or less). It can also be used during normal tracking to reduce the amount of time the beam is dithered, thereby reducing tracking loss.

The antenna is an array of 19 capacitively fed stacked patches. The assembly is illustrated in Figure 3. The elements are arranged in a triangular lattice as shown. The 19-way power divider and 18 phase shifters (the center element does not use a phase shifter) are located on the lowest microstrip board. The power dividers are microstrip Wilkinson dividers. Three-bit distributed-element phase shifters are used. The 180 and 90 degree bits are reflection bits, and the 45 degree bit is a loaded line bit. Reflection and loaded line bits are chosen to minimize the diode count (switched line bits use twice as many diodes). The phase shifter outputs are passed through to the driver element board. This layer holds the lower elements of the stacked patches and the quadrature hybrids used to achieve circular polarization. The element and hybrid are illustrated in Figure 4. Capacitively fed stacked patches are used because they meet the 7% bandwidth requirement and are relatively inexpensive to manufacture. The upper patch element is mounted on a layer of PTFE which is separated from the driver element board by a dielectric spacer. The patch sizes, spacer thickness, and driven element board thickness are adjusted to yield optimum VSWR and pattern behavior for the element. The array is covered with a thin radome which provides environmental protection.

An analysis has been conducted to determine the cost of manufacturing the antennas in quantities of 10,000 per year. The cost figure for this production rate is \$1620 per unit. This figure is of medium confidence (+/- 25%). Using some optimistic assumptions, this figure could drop to \$1000 - \$1300. The changes made in these lower cost figures could result in performance degradation of 1 or 2 dB.

FIGURE 3 ANTENNA SANDWICH

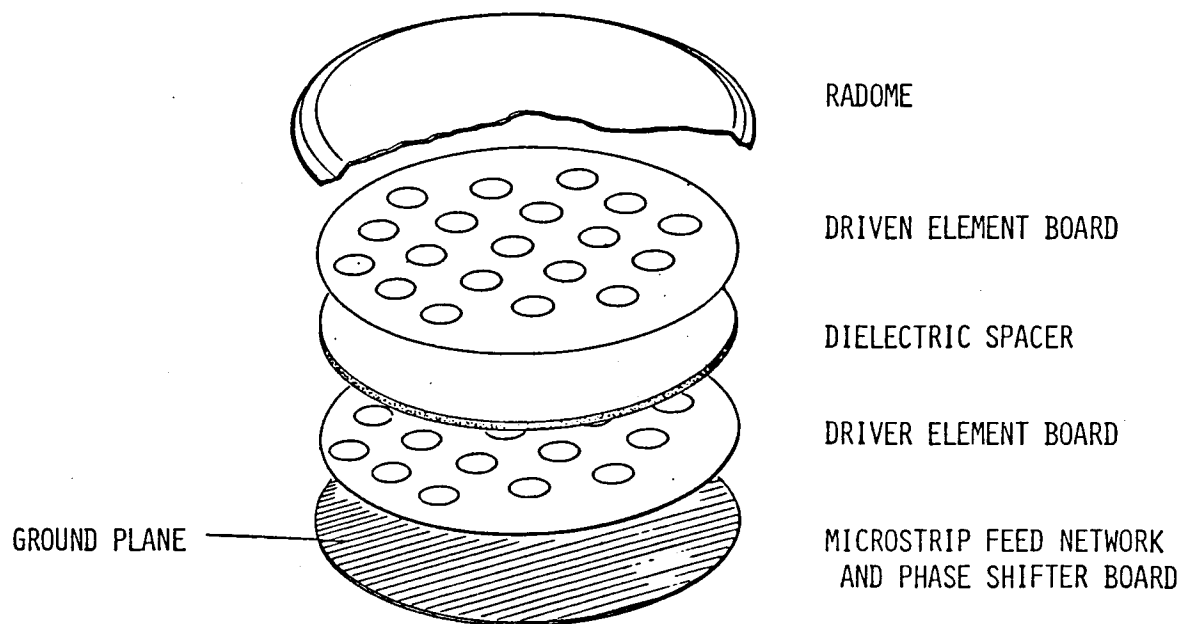
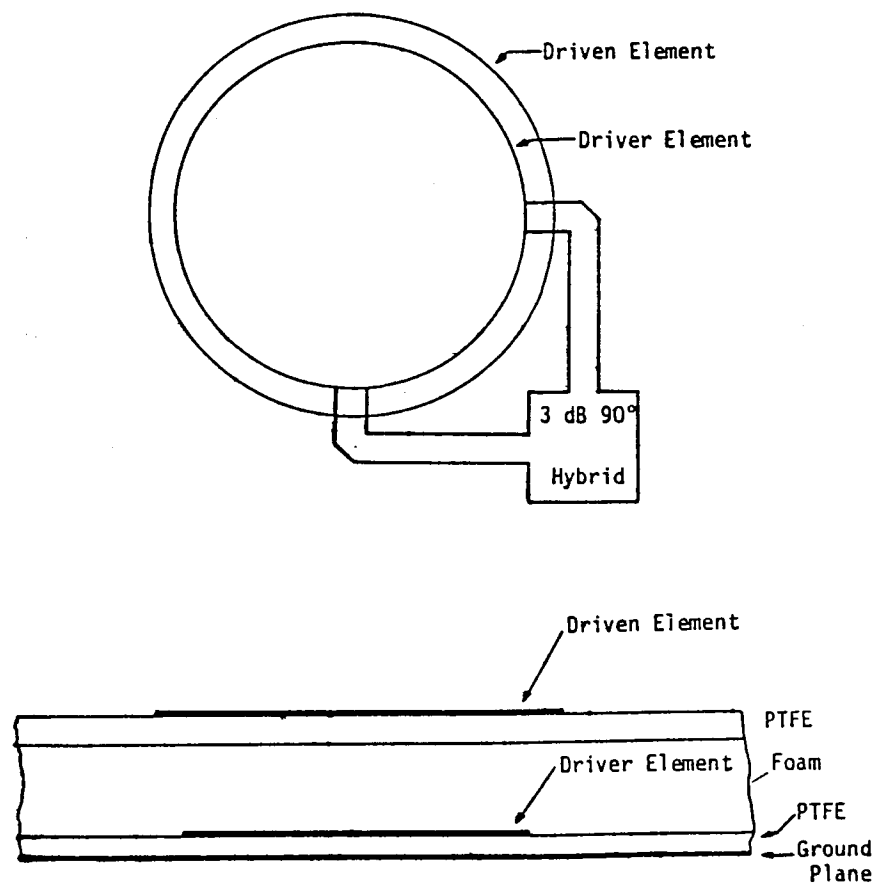


FIGURE 4 ELEMENT DESIGN



The assembled breadboard antenna and pointing system are shown in Figure 5. The RF portion of the antenna is similar to what would be used in an actual production antenna. The pointing system is a development unit and is not representative of the end product.

MECHANICAL/ENVIRONMENTAL CONSIDERATIONS

The antenna is packaged to meet the specific requirements of the mobile vehicle environment. The unit is quite strong. It has shown the ability to support the weight of an adult, in addition to resisting heavy blows and scraping from a ice scraper. The unit has very good sealing against external moisture. Furthermore, the use of hermetically sealed diodes insures that any moisture which can enter the unit will not result in degradation in performance. The unit is designed to be easily serviced. As shown in Figure 6, the antenna opens to provide access to all of the cables and phase shifter components. The Ball Aerospace breadboard MSAT antenna is representative of the technology which will meet MSAT environmental requirements as well as electrical.

RESULTS

Static testing has been conducted wherein the antenna is scanned throughout the coverage region. Gain measurements for the antenna range from 13.4 dB at 60 degrees elevation to 8-9 dB (depending on azimuth angle) at 20 degrees elevation. It is noted that these gain figures are also valid to 1530 MHz, which allows the antenna to function throughout the WARC LMSS frequency bands. Dynamic system testing was conducted with JPL's receiver. The acquisition routine works very well down to 40 dB Hz C/No. The tracking routine functions very well to 35 dB Hz for a stationary platform and 40 dB Hz for a platform rotation speed of 45 degrees per second. The system also shows very good immunity to fading. 5 dB fading at a rate of 400 Hz has a minimal effect on acquisition or tracking functions.

CONCLUSION

The MSAT-X breadboard antenna development has been quite succesful in demonstrating the feasibility of using an electronically steered antenna in the mobile MSAT application. While the antenna does not meet the gain spec, it does deomonstrate the required functions for the system, including pointing the beam, acquiring the satellite and tracking it during open and closed loop tracking conditions. BASG has been working with JPL to identify the areas where improvement is required to improve the antenna performance. We believe performance improvement of 1 dB or more could be obtained using the techniques identified.

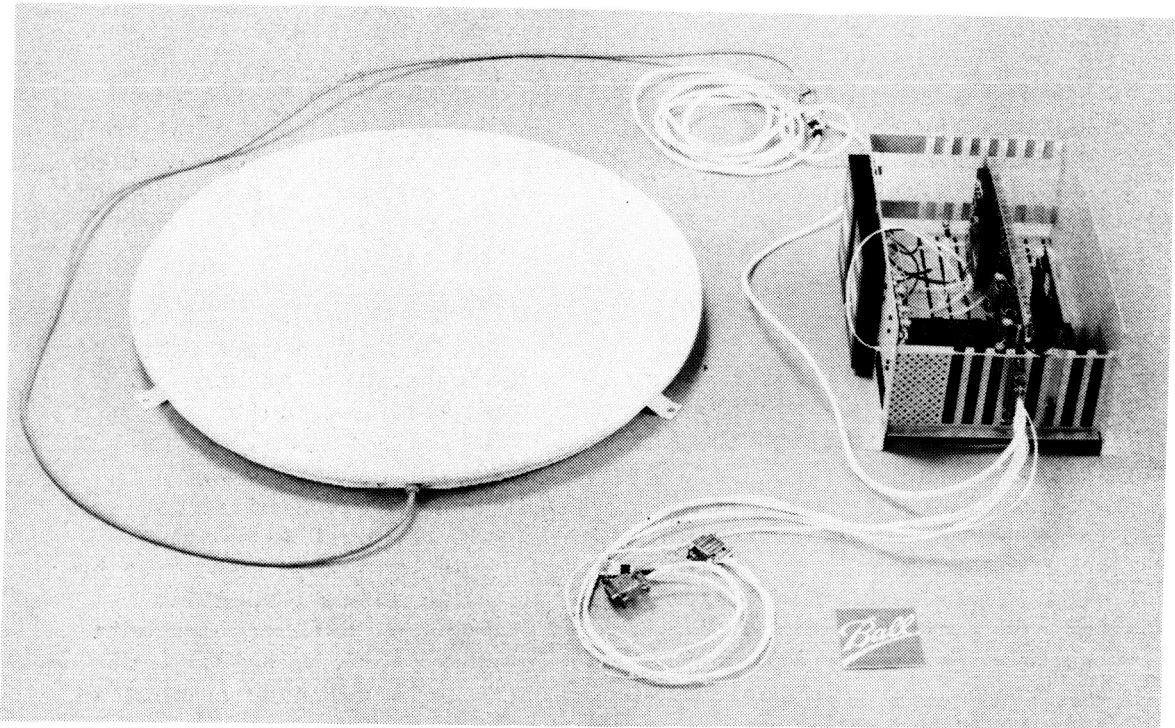


FIGURE 5: MSAT Breadboard Antenna with Pointing System

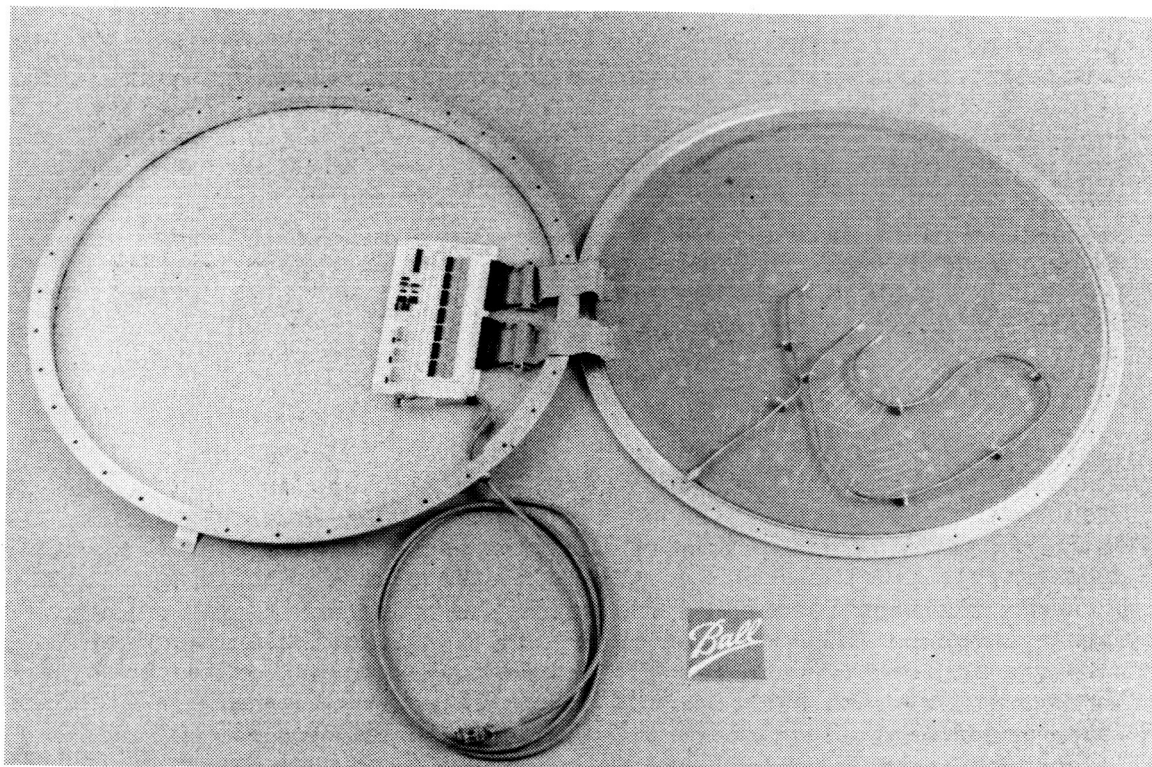


FIGURE 6: MSAT Antenna in Open Configuration for Service